13.5 THE 29 JUNE 1998 DERECHO ACROSS CENTRAL ILLINOIS: ISSUES ASSOCIATED WITH NON-DESCENDING TORNADIC AND NON-TORNADIC VORTEX EVOLUTION

[1]Bradley D. Ketcham and [2]Ron W. Przybylinski

[1] Weather Forecast Office
1362 State Route 10
Lincoln IL 62656

[2] Weather Forecast Office
12 Research Park Dr.
St. Charles, MO 63304

1. INTRODUCTION

In the late afternoon of 29 June 1998, a line of hybrid High-Precipitation (HP) supercells (Moller et al. 1990) moved across much of Iowa before becoming a Quasi-Linear Convective System (QLCS Tessendorf and Trapp 2000) over eastern sections of the state and northwest Illinois. The convective system moved southeast across central Illinois and caused extensive areas of wind damage and spawned weak tornadoes. Wind gusts were estimated at 35-45 m s^{-1} (80-100 mph), while seven confirmed tornadoes caused F1-F2 damage to numerous farmsteads, homes, businesses, and large electrical towers and lines. Dollar estimate of the tornadic and straight-line wind damage exceeded twelve million dollars. The large number of severe weather reports met or exceeded the criteria to classify this system as a Derecho (Johns and Hirt 1987). A number of studies have been completed on cyclonic circulations located along and north of the apex of a bow echo and/or near low-level outflow boundary - convective line intersections (Funk et al. 1998; Przybylinski et al. 2000). This paper will focus on the evolution of four of six cyclonic circulations between 2056-2200 UTC (hereafter all times UTC) which formed near a low-level boundary-convective line intersection or along the leading edge (apex of the bow echo and northward) during the early part of bowing across central Illinois. We will also elaborate on the importance of an old low-level boundary intersecting the northern end of the large bowing segment. This feature has been documented in several other cases and is a critical issue to early vortex growth and longevity.

2. SYNOPTIC AND MESOSCALE ENVIRONMENT

Convection initiated in northeast Nebraska as a cluster of High-Precipitation (HP) supercells along a stationary frontal boundary extending from western Iowa into northern Illinois. The area was characterized by low-level warm advection, moderate instability and deep layer shear. Slater Iowa profiler data (not shown) at 1500 showed deep layer shear over central Iowa at mid morning with 0-5 km bulk shear values reaching 26 m s^{-1}. The thunderstorm complex also formed in the right entrance region of a 300 mb upper-level jet across the western Great Lakes region (not shown). The surface analysis at 1900 showed a stationary front extending from east-central Iowa through northern Illinois to just north of Chicago IL (ORD). An old low-level boundary generated by a convective complex the preceding night extended from 30 km south of Moline (MLI) IL to just north of Peoria (PIA) IL and eastward into northwest Indiana. The visible satellite image at 1900 (Fig. 1) showed the cumulus field reflecting the location of the old boundary. An additional boundary from the previous nights convection complex also

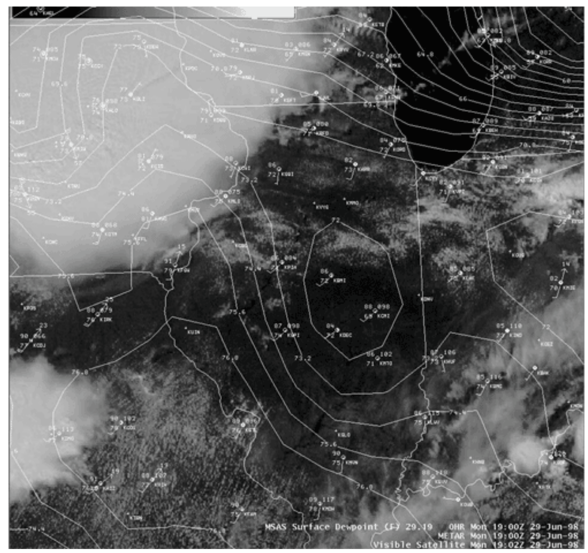

Figure 1. GOES 8 visible satellite imagery at 1900 UTC. Surface data plots and dewpoint contours are overlaid on imagery.

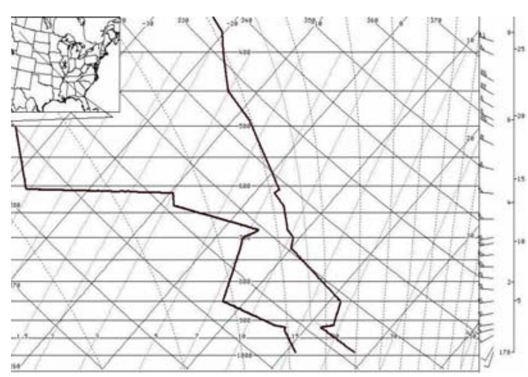

Figure 2. Skew-T Log-P sounding from Lincoln Illinois (KILX) at 1800 UTC; 29 June 1998.

Corresponding author address: Bradley D. Ketcham, 1362 State Route 10, Lincoln, IL 62656; e-mail: Brad.Ketcham@noaa.gov

extended from MLI to Springfield (SPI) to southwest Indiana. A noticeable dewpoint discontinuity existed with this boundary. Dewpoints greater than 24/C pooled south and west of this low-level boundary. The vigorous mesoscale convective complex (MCS), discussed here moved east-southeast and eventually traveled along the MLI to PIA to Indiana oriented outflow boundary.

The 1800 Lincoln Illinois (KILX) sounding revealed moderate instability with a Convective Available Potential Energy (CAPE) of 1630 J/Kg, Convective Inhibition (CIN) of -45 J/Kg and lifted index of -5 using the mean mixed parcel layer (Fig.2). Estimated surface based CAPE by mid afternoon exceeded 4000 J/Kg.] Magnitudes for 0-3 (0-5) km bulk shear from the 1800 KILX sounding were 14 (16) m s^{-1} respectively (moderate shear). Given storm motion of 290/ 22 m s^{-1} Storm Relative Helicity (SRH) values from the WSR-88D Velocity Wind Profile (VWP) at KILX at 2103 for the 0-2 (0-3) km layers were 168 (165) $m^2 s^{-2}$ respectively.

3. STRUCTURE AND EVOLUTION

3.1 Broad Overview

As the QLCS entered northwest and west-central Illinois at 2045, reflectivity characteristics showed the presence of a mature bow echo with an area of broken convection representing the warm advection wing, extended east from the northern end of the bow (Smith 1990) (Fig. 3). A larger overview of the reflectivity and circulation characteristics of the 29 June QLCS over Iowa and Illinois is shown by Arnott and Atkins (2002) elsewhere in this volume. The area of broken convection was along and north of the synoptic-scale warm frontal boundary. A nearly linear convective segment was noted along the forward flank of the larger bow and small isolated convective cells extended 20 km east from the northern end of this segment. These isolated cells appeared to be anchored to the old low-level boundary from the convective complex the preceding night. The boundary was nearly orthogonal to the convective line segment extending east across north-central Illinois.

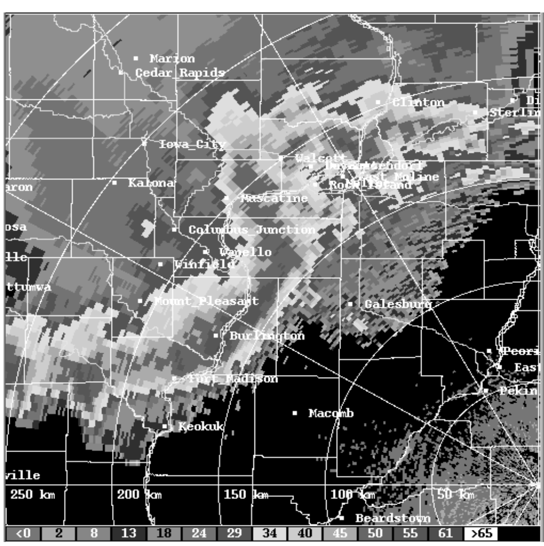

Figure. 3. WSR-88D plan-view reflectivity image from Lincoln IL (KILX) (0.5° slice) for 2045 UTC; 29 June 1998.

Reflectivity cross-sections taken between 2040 - 2102 (not shown) revealed a classic multicellular evolution (Smull and Houze 1987) with new convective towers rapidly forming along the system's leading edge. Storm-relative velocity (SRM) data revealed a strong but gradual sloping mesoscale rear inflow jet extending from the trailing flank of the leading convective line rearward towards the rear of the convective system with a steep ascending branch. A strong Mid-Altitude Radial Convergence (MARC - Schmocker et al. 1996) velocity signature was detected along the system's leading edge between 2040 - 2102 within the 3.5 - 6.5 km layer. Magnitudes of MARC exceeded 40 m s^{-1} suggesting a strong signal for enhanced damaging winds.

3.2 Circulations

Six cyclonic circulations were observed from 2056 through 2200 as the large bow echo moved southeast across northwest and central Illinois. The tracks of four of the six convective-scale vortices and squall line positions are shown in figure 9 and will be discussed in the following sections.

3.2.1. Circulations 1 and 2 (Knox County Circulations)

The first two cyclonic circulations formed near the intersection of the old low-level boundary and northern end of the quasi-linear convective line segment in the vicinity of Galesburg Illinois in Knox County at 2056. Recent work completed by Markowski et al. 1998 and others have shown that low-level boundaries are sources of local vorticity and preferred regions of mesocyclogenesis. Initially, Circulation 1 (C1) was relatively deep (5 km) with a mean core diameter of 5 km and rotational velocities (Vr) of 19 (16) m s^{-1}at 0.5° (1.5°) slices (not shown). At its midpoint, C1 deepened to 6 km with mean Vr values of 19 m s^{-1}. However, the core diameter also increased to 10 km at this time. C1 revealed a relatively short lifetime of twenty-five minutes.

Circulation 2 (C2) formed 4 km south of C1 or 130 km northwest of KILX and was only detected within the lowest slice at 2056. The plan-view reflectivity / storm-relative velocity (SRM) images shows C1 and C2 at 2103 (Fig. 4). C2's core diameter (2 km) was significantly smaller than C1 with Vr values of 15 m s^{-1} at this time. During the subsequent five volume scans, C2 showed non-descending characteristics at it reached a height of 10.5 km at 2126 (Fig. 6). These vortex characteristics were similar to several circulations identified by Wolf (2000) earlier in the MCS's lifespan over eastern Iowa. Greatest increase in Vr values were confined to the lowest 3 km where magnitudes reached 30 (32) m s-1 at 0.5° (1.5°) slices at 2126. Plan view reflectivity - storm-relative velocity images for 2126 are shown in figure 5. A smaller vortex exhibiting gate-to-gate shears within C2 was detected between 2120 and 2126. Magnitudes of delta-V ranged from 59 (57) m s^{-1} at 0.5 (1.5°) slices at 2120 and below 53 m s^{-1} at 2126. C2's mean core diameter gradually increased to 7.7 km by 2114, then dropped to 4.5 km at 2120. A *'non-supercell'* tornado occurred from 2120 through 2126 and caused F1 damage. Studies completed by Przybylinski et al. (2000) have shown that non-supercell tornadoes associated with non-descending vortices may occur just preceding the circulation's maximum depth, strongest rotation within the lowest 3 km, and a sudden drop in the mesocyclone's core diameter. C2 persisted for over 50 minutes along the northern end of the convective line segment and in the vicinity of the old low-level boundary. It exhibited the longest lifetime of all the circulations studied

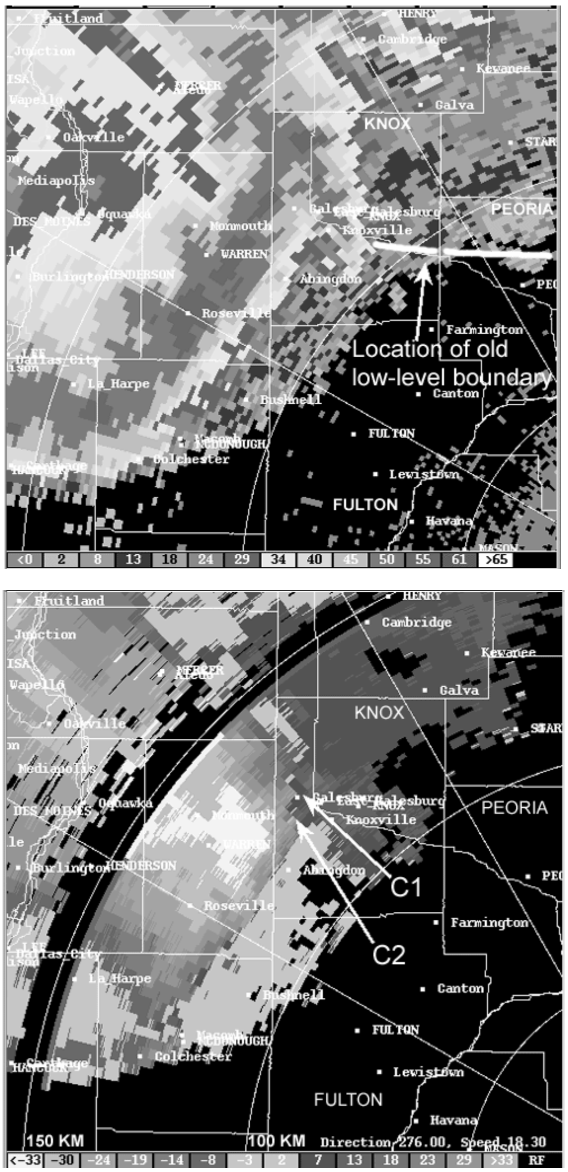

Figure 4. WSR-88D plan-view reflectivity (top) / storm-relative velocity (bottom) from KILX (0.5/ slice) at 2103 UTC; 29 June 1998. Circulations 1 and 2 are highlighted C1 and C2 respectively.

during this period. Both C1 and C2 were the first two convective-scale vortices documented after 2045 across this part of the convective line and preceded subsequent circulations along the line by as much as 10 to 15 minutes.

A classic line-end vortex (C2a) formed at 2138 in the vicinity of C2 over north-central Illinois. During the early stages of C2a (not shown), the vortex originated between 4 and 7 km with mean Vr magnitudes of 26 m s^{-1} and a relatively broad core diameter of 15 km. During the subsequent four volume scans the vortex descended and extended from 1 to 6 km at 2155. The strongest Vr were identified within the lowest 2 km of the vortex where mean magnitudes were 24 m s^{-1} while slightly weaker values (20 m s^{-1}) were detected above. [The core diameter over the lower part of the vortex increased to 22 km at 2155 and over 30 km after 2210]. During the presence of C2a, the convective line accelerated to speed greater than 25 m s^{-1} between 2133 and 2203 while convective towers along this part of the line were shallower compared to other parts of the convective line. Numerical simulations completed by Weisman (1993) showed that line-end vortices act as a focusing effect resulting in the enhancement of the flow between the cyclonic and anti-cyclonic members. The greatest degree of wind damage was tracked along the southern periphery of the northern line-end vortex where estimated wind gusts exceeded 40 m s^{-1} from PIA through Bloomington IL (BMI).

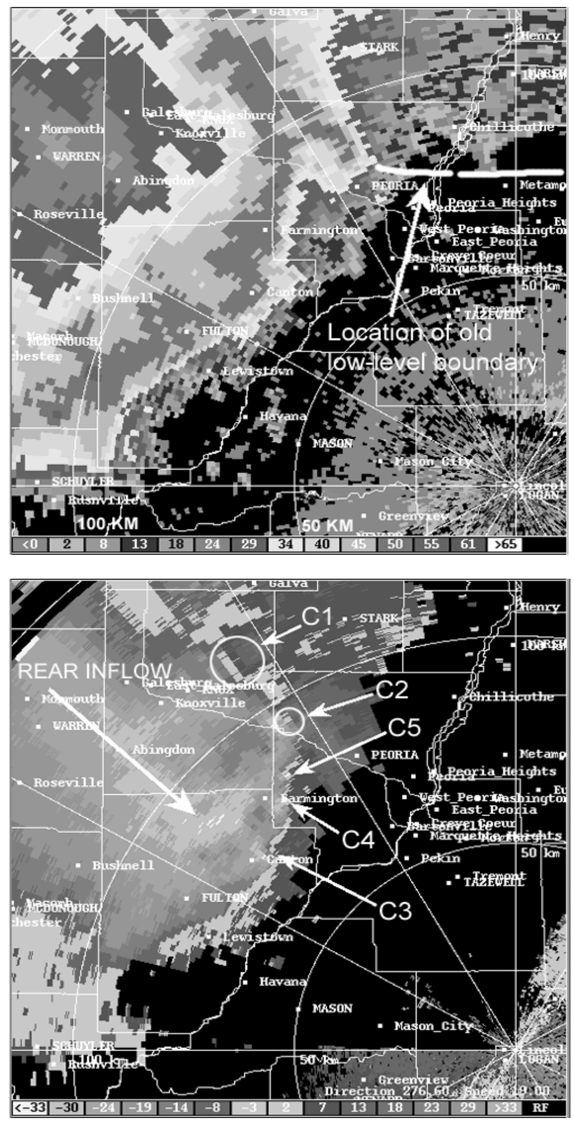

Figure 5. Same as Fig.4. except for 2126 UTC. Circulations 2 through 5 are identified.

3.2.2 Circulation 3 (Tazewell County Vortex)

Circulation 3 rapidly formed near the apex of the developing

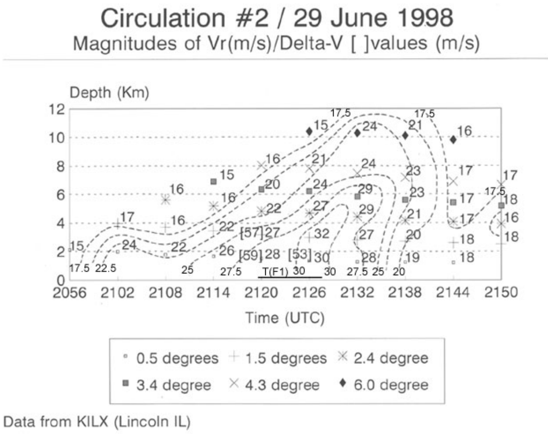

Figure 6. Rotational Velocity (Vr) time-height trace for Circulation 2. Magnitudes of Vr are in m s^{-1} . [ ] represent the identification of gate-to-gate couplet. Time is represented in UTC and height is shown in km.

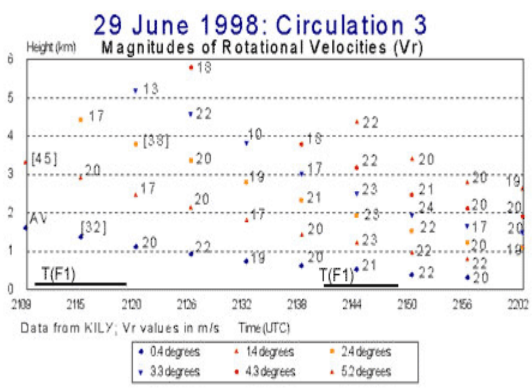

Figure 7. Same as Fig. 6 except for Circulation 3.

bowing segment at 2109. This vortex likely manifested from a presumed release of horizontal shearing instability along the leading edge of the convective system (Carbone 1983; Przybylinski 1995). Aliased velocities masked the vortex structure at the 0.5° slice at this time, however, a gate-to-gate couplet with delta-V values of 45 m s^{-1} was noted at the next step elevation (1.5° slice). Core diameter was below 1.0 km. C3 quickly developed in a non-descending mode and was associated with a Tornadic Vortex Signature (TVS) during the first 10 minutes of its lifetime (Fig. 7). The overall evolution of this vortex resembled similar characteristics to observations of a tornadic non-descending TVS recorded by Trapp et al. 1999. A tornado occurred during the very early stages of C3 (TVS - period of non-descending) and produced F1 damage over northwest sections of Fulton County Illinois. At 2126, C3's core diameter increased to 4.6 km and increased to a depth of 6 km. After 2126, C3's depth dropped to 4 km while the strongest rotation was confined to the lowest 3 km with mean Vr magnitudes of 18 m s^{-1}. No tornadic activity was reported when the vortex height dropped between 2126 and 2132. C3 increased in strength and depth a second time and peaked at 2144 with an overall height of 5 km and mean Vr values of 22 m s^{-1}. Simultaneously, the C3's core diameter fell from 3.7 (2138) to 1.9 km (2144). A tornado occurred between 2138 and 2150 and caused damage (F1 intensity) to large transmission towers and lines over parts of central Tazewell County (25 km south of PIA). C3's depth dropped a second time after 2144 but continued to maintain strong rotation within the lowest 2.5 km with mean Vr magnitudes of 21 m s^{-1}. The vortex significantly weakened after 2156 and showed cyclonic divergent characteristics with a mean core diameter greater than 7 km. A new circulation formed 5 km southeast of C3 at 2156 and remained near the apex of the larger bow through 2230. Total lifetime of C3 was fifty-three minutes.

3.2.3 Circulation 4

The fourth circulation (C4) under study formed approximately 10 km northwest of the apex of the bow (and C3) along the cyclonic shear side, and along the leading low-level reflectivity gradient of the large bowing structure. C4 initially formed at 2121 below 2.5 km, revealed Vr values of 17 m s^{-1} and exhibited a mean core diameter of 2 km. C4's evolutionary characteristics were quite similar to C2. The circulation sharply deepened to a height of 8.5 km within the next twenty-five

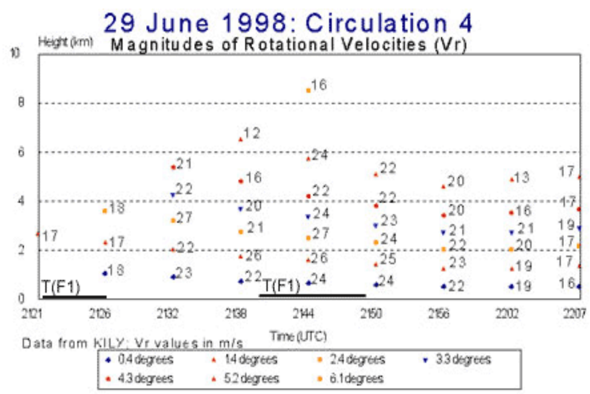

Figure 8. Same as Fig. 6 except for Circulation 4.

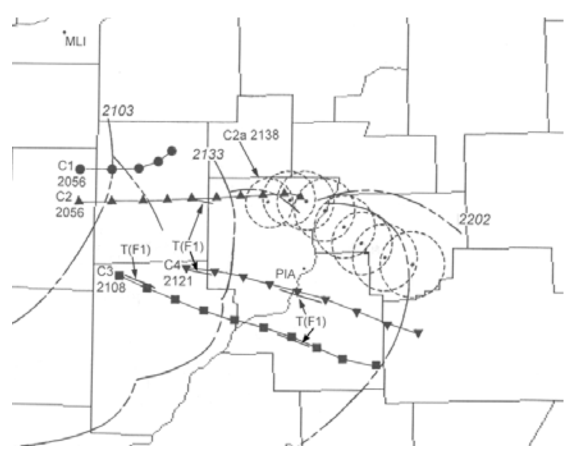

Figure 9. Map of circulation tracks 1 through 4. Black symbols along each of the tracks represent 5 min interval circulation positions with the beginning time in UTC indicated. Squall line positions are denoted approximately every 30 minutes.

minutes, while the strongest rotation exceeding 25 m s^{-1}

was confined to the lowest 3 km (Fig. 8). The mean core diameter slightly expanded to 4 km ten minutes after it was initially detected and remained at this diameter through 2144. Weak tornadoes (F1 damage) occurred at the very early stages of C4, and just before the time of maximum depth and strongest rotation within the lowest 3 km. Several homes and businesses in Morton IL (5 km southeast of PIA) were damaged by the second tornado. After 2202 the vortex weakened as its mean core diameter increased to 8 km. Total lifetime of C4 was forty-five minutes.

4. SUMMARY

A detailed study of four of the six circulations associated with the 29 June 1998 QLCS over north-central Illinois was completed. The investigation showed that the first two circulations formed near the intersection of an old low-level boundary generated by convection the preceding night and the northern part of a quasi-linear convective line segment embedded within a larger bow echo. The first circulation exhibited a relatively deep core throughout much of its lifetime. However, it failed to spawn a tornado. Circulation 2 initially developed at low-levels (below 3 km), revealed non-descending characteristics and was the longest lived circulation of the four. A weak tornado occurred just preceding the core's greatest depth, maximum rotation below 3 km and lowering of the core diameter. Circulation 3 formed near the apex of the bow and revealed non-descending characteristics during its early stages and later half of its lifetime. Non-supercell tornadoes occurred during the very early stages and again near the second peak of maximum vortex depth and strongest rotation below 3 km. Circulation 4's evolution was quite similar to that of Circulation 2 revealing non-descending characteristics. Weak tornadoes occurred during the very early stages and again just preceding the circulation's greatest depth and strongest rotation within the lowest 3 km. However, the core diameter did not lower as much compared to Circulation 2's during the period of maximum vortex height.

All the circulations under study also occurred from the bow apex northward. However, Circulations 3 and 4 mainly moved in the same direction of the bow and did not merge with Circulation 2 or 2a.

The findings presented have forecast implications. The intersection of the boundary with the convective line has been shown to enhance tornadic potential and should be watched closely for development. Second, the forecaster can focus his attention for the potential for tornado warnings from the bow apex northward, however, the issuance of such warnings can become problematic since weak tornadoes frequently occur during the very early stages of the circulation's lifetime. Last, the circulation trends also reveal that a second weak tornado may occur just preceding the core's greatest depth, with strong rotation within the lowest 3 km, and varying degrees of lowering of the core diameter giving forecasters limited short-term predictability. This type of vortex evolution and time of tornado occurrence has been documented in other cases (Przybylinski et al. 2000). Much more work is needed to understand the genesis mechanisms and overall characteristics of convective-scale vortices associated with QLCSs. It is hoped that future observational studies, improved numerical simulations, and findings from the BAMEX project will provide answers to the many questions raised.

5. ACKNOWLEDGMENTS

The authors are grateful to Mr. Llyle Barker (SOO at WFO Lincoln) and Mr. Gary Schmocker (forecaster at WFO St. Louis) for their beneficial suggestions on improving the manuscript. Additional thanks goes to Mr. Ernie Goetsch (MIC) WFO Lincoln and Mr. Steven Thomas (MIC) WFO St. Louis for their support in this study.

6. REFERENCES

Arnott, J.M., and N.T. Atkins: 2002: Tornadogenesis with Quasi-Linear Convective Systems. Part 1: Radar and storm damage analysis of the 29 June 1998 derecho. Preprints, *21st Conf. on Severe Local Storms.* San Antonio, TX. Amer. Meteor. Soc. this volume.

Carbone, R.E. 1983: A severe frontal rainband. Part II: Tornado parent vortex circulation. *J. Atmos. Sci.* **40**, 2639-2654.

Funk, T.W., V.L. DeWald, and Y.J. Lin: 1998 A detailed WSR-88D Doppler radar evaluation of a damaging bow echo event on 14 May 1995 over north-central Kentucky. Preprints, *19th Conf. on Severe Local Storms*. Minneapolis MN, 436-439.

Johns, R.H., and W.D. Hirt, 1987: Derechos: Widespread convectively-induced windstorms. *Wea. Forecasting*, **2**, 32-49.

Markowski, P.M., E. N. Rasmussen, and J.M. Straka, (1998): The occurrence of tornadoes in supercells interacting with boundaries during VORTEX-95. *Wea. Forecasting,* **13**, 852-859.

Przybylinski, R.W., 1995: The bow echo. Observations, numerical simulations and severe weather detection methods. *Wea. Forecasting,* **10**, 203-218.

________, G.K. Schmocker, and Y.J. Lin: 2000: A study of storm and vortex morphology during the 'Intensifying Stage' of severe wind mesoscale convective systems. Preprints, *20th Conf. on Severe Local Storms.* Orlando, FL., Amer. Meteor. Soc. 173-176.

Schmocker, G.K., R.W. Przybylinski, and Y.J. Lin: 1996: Forecasting the initial onset of damaging downburst winds associated with a mesoscale convective system (MCS) using the mid-altitude radial convergence (MARC) signature. Preprints, *15th Conf. on Weather Analysis and Forecasting,* Norfolk VA, Amer. Meteor. Soc. 306-311.

Smith, B.E. 1990: Mesoscale structure of a derecho-producing convective system: The southern Great Plains storms of May 4, 1999. Preprints, *16th Conf. on Severe Local Storms,* Kananaskis Park, AB, Canada, Amer. Meteor. Soc. 428-433.

Smull, B.F., and R.A. Houze, 1987: Rear inflow in squall lines with trailing stratiform precipitation. *Mon. Wea. Rev.* **115**, 2869-2889.

Tessendorf, S.A., and R.J. Trapp: 2000: On the climatological distribution of tornadoes within quasi-linear convective systems. Preprints, *20th Conf. on Severe Local Storms,* Orlando, FL. Amer. Meteor. Soc. 273-276.

Trapp, R.J., E.D. Mitchell, G.A. Tipton, D.W. Effretz, A.J. Watson, D.L. Andra, and M.A. Magsig, 1999: Decending and non-descending tornadic vortex signatures detected by WSR-88Ds. *Wea. Forecasting*, **14**, 625-639.

Weisman, M.L. 1993: The genesis of severe long-lived bow echoes. *J. Atmos. Sci.,* **50**, 645-670.

Wolf, R.A., 2000: Characteristics associated with the 29 June 1998 Derecho in eastern Iowa. Preprints, *20th Conf. on Severe Local Storms,* Orlando, FL., Amer. Meteor. Soc., 56-59.